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U.S. PATENT APPLICATION

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Invention: DIFFUSION BONDED WIRE MESH HEAT SINK

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SPECIFICATION

DIFFUSION BONDED WIRE MESH HEAT SINK

BACKGROUND

[0001] **1. FIELD OF THE INVENTION**

[0002] This invention pertains to heat sinks, and particularly to heat sinks which are cooled by a circulating fluid.

[0003] **2. RELATED ART AND OTHER CONSIDERATIONS**

[0004] Various types of equipment create or release heat during operation. In some cases the heat can be injurious to the equipment or its environment (e.g., other equipment or components in proximity to the heat-generating or heat-releasing equipment). Accordingly, attempts have been made in some such cases to cool the equipment and/or its environs. Common cooling techniques include circulation of a cooling fluid around or near the source of heat. For example, fans have been used to blow cooling air around a heat-generating component of a system. Alternatively, heat pipes or other types of heat sinks have been placed in contact or nearby the heat source for the purpose of dissipating the heat using, e.g., circulating air.

[0005] Among the types of equipment prone to heat generation/release are some electronic components, such as microprocessors, for example. As microprocessor manufacturers are running the microprocessor chips at higher and higher frequencies in order to obtain maximum performance, the chips can build up enough heat to cause failures. In fact, the heat can become so great in many chips that conventional means of cooling (e.g., fans and heat pipes) are not sufficiently effective.

[0006] In view of the inadequacy of conventional cooling techniques, fluid cooling of heat generating/releasing components (e.g., electronic chips) is gaining momentum. For example, for cooling purposes a fluid is pumped through a heat sink in contact with the chip die to pick up heat from the chip die. The fluid is then pumped to a heat exchanger for cooling the fluid before the fluid is routed back to the heat sink to pick up and remove more heat.

[0007] Some fluid-accommodating heat sinks employ microchannel technology. That is, the heat sinks have "microchannels" through which the cooling fluid travels as it is pumped. The microchannels are very small channels formed in or on a heat sink surface, or the chip die. The heat sink surface with the microchannels may be flush with or otherwise in contact with a surface of a device to be cooled (e.g., chip die).

[0008] Despite their proven potential for handling high heat fluxes, microchannel-based heat sinks have not found widespread commercial use, possibly due to the very high pressure drops encountered in the microchannels. High pressure drops necessitate the use of relatively large pumps with significant power requirements, noise, reliability issues ,and associated costs.

[0009] Moreover, there can be a problem if bubbles form in microchannel-type heat sinks. When a bubble forms in a microchannel of a heat sink, the bubble tends not to exit the channel. Instead, the bubble remains essentially stationary in the microchannel. Since the remaining bubble occludes the cooling fluid flow, a hot spot may develop in or on the device being cooled. If the hot spot grows significantly, the device being cooled may fail.

[0010] What is needed, therefore, and an object of this invention, is an efficient and effective heat sink.

BRIEF SUMMARY

[0011] A heat sink assembly comprises a monolithic heat sink monolith and a cover. The monolithic heat sink monolith comprises a thermal transfer plate and a wire mesh diffusion bonded to form a monolithic structure, i.e., totally uniform material. The thermal transfer plate of the monolith and the cover cooperate to define a heat transfer chamber. The wire mesh structure of the monolith is configured and positioned in the chamber to provide a tortuous, heat conduction path for fluid (e.g., a coolant) which turbulently travels from an inlet of the chamber to one or more outlets of the chamber.

[0012] The monolithic heat sink comprises a wire mesh formed into a tightly wound spiral which is fused by diffusion bonding (rather than by soldering) onto the thermal transfer plate, as well as being fused to itself. The diffusion bonding of the wires

provides the wire mesh structure with many and appropriately sized interstices, making it easier to push the fluid through the heat sink assembly and thereby significantly reducing the size and power of the pump which pushes the fluid. Stated differently, the diffusion bonded mesh functions similarly to the microchannel, but with, e.g., greater numbers of fluidic paths and thus far less pressure drop. Further, the heat transfer efficiency is increased due to the fact that the diffusion bonded wire mesh structure has such a large surface area, up to five to ten times more that a standard microchannel heat sink

[0013] The wire mesh structure can be secured or adhered to the thermal transfer plate by numerous conventional techniques such as (for example) soldering, welding, radio frequency (RF) melting, and adhesives which are cured or activated (e.g., by heat, by voltage, etc.). Preferably the wire mesh structure is diffusion bonded to the thermal transfer plate in a same operation in which the wires of the wire mesh structure are bonded together. The diffusion bonding of the wire mesh structure to the thermal transfer plate to create the monolith allows for higher efficiency in transferring heat from the thermal transfer plate to the wire mesh structure.

[0014] Within the chamber the diffusion bonded wire mesh structure can have various configurations for providing an exposure interface between fluid pumped through the chamber and the diffusion bonded wire mesh. In one example embodiment, the diffusion bonded wire mesh structure is folded in an essentially serpentine configuration within the chamber. A path of the fluid in the chamber from the inlet to the outlet is preferably not parallel to the fold axes, and more preferably is substantially perpendicular to the fold axes. In one non-limiting implementation of this embodiment in which the housing has an essentially parallelepiped shaped and includes the thermal transfer plate and four side walls, the inlet and the outlet are provided on opposing sidewalls that are parallel to the fold axes.

[0015] In another example embodiment, the diffusion bonded wire mesh structure has an essentially spiral configuration within the chamber. In yet another example embodiment, the diffusion bonded wire mesh structure has an essentially circular configuration within the chamber, and preferably is configured to comprise plural concentric rings within the chamber. In certain example implementations of the spiral and circular/concentric embodiments in which the housing has an essentially

parallelepiped shape, the housing includes the thermal transfer plate, four side walls, and a port wall which is opposite the thermal transfer plate, with the inlet and the outlet being provided on the port wall. In one implementation, the inlet and outlet communicate through respective channels formed in the port wall so that fluid travels through the channels in a direction which is essentially parallel to a plane of the thermal transfer plate. In this manner, fluid is introduced centrally into the chamber and pumped to one or more corners of the housing. In embodiments in which the housing has plural outlets, downstream from the outlets the outlets may be connected to a common discharge tube.

[0016] The heat sinks are useful in a heat dissipation system in which the thermal transfer plate of the heat sink is situated in heat conducting relation with a body to be cooled, and which further includes a heat exchanger and a pump. The pump serves to move fluid through a circulation path including the heat sink and the heat exchanger. The circulation path is configured so that after the heat is transferred to the fluid in the heat sink, the fluid is cooled by the heat exchanger prior to the fluid being circulated back to the heat sink.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] Fig. 1A is a perspective top and side view of a heat sink assembly according to a first example embodiment.

[0018] Fig. 1B is a bottom view of the heat sink assembly of Fig. 1A taken along the line 1B – 1B.

[0019] Fig. 1C is a side view of the heat sink assembly of Fig. 1A taken along the line 1C – 1C.

[0020] Fig. 2A is a perspective top and side view of a heat sink assembly according to a second example embodiment.

[0021] Fig. 2B is a bottom view of the heat sink assembly of Fig. 2A taken along the line 2B – 2B.

[0022] Fig. 2C is a side view of the heat sink assembly of Fig. 2A taken along the line 2C – 2C.

[0023] Fig. 3A is a perspective top and side view of a heat sink assembly according to a second example embodiment.

[0024] Fig. 3B is a bottom view of the heat sink assembly of Fig. 3A taken along the line 3B – 3B.

[0025] Fig. 3C is a side view of the heat sink assembly of Fig. 3A taken along the line 3C – 3C.

[0026] Fig. 4A is a top view of a monolith for a heat sink assembly according to a fourth example embodiment.

[0027] Fig. 4B is a side view of the monolith of Fig. 4A.

[0028] Fig. 4C is a bottom view of a cover for the monolith of Fig. 4A.

[0029] Fig. 4D is a front side view of the cover of Fig. 4C taken along the line 4D – 4D.

[0030] Fig. 4E is a left side view of the cover of Fig. 4C.

[0031] Fig. 4F is a front side view of the cover of Fig. 4C taken along the line 4F – 4F.

[0032] Fig. 5A is a top view of a monolith for a heat sink assembly according to a fifth example embodiment.

[0033] Fig. 5B is a side view of the monolith of Fig. 5A.

[0034] Fig. 5C is a bottom view of a cover for the monolith of Fig. 5A.

[0035] Fig. 5D is a front side view of the cover of Fig. 5C taken along the line 5D – 4D.

[0036] Fig. 5E is a right side view of the cover of Fig. 5C.

[0037] Fig. 6A – Fig. 6E are schematic views of differing, example heat dissipation systems which include a representative, generic heat sink assembly.

DETAILED DESCRIPTION

[0038] In the following description, for purposes of explanation and not limitation, specific details are set forth such as particular architectures, interfaces, techniques, etc. in order to provide a thorough understanding of the present invention. However, it will be apparent to those skilled in the art that the present invention may be practiced in other embodiments that depart from these specific details. In other instances, detailed descriptions of well-known devices, circuits, and methods are omitted so as not to obscure the description of the present invention with unnecessary detail.

[0039] Heat sink assemblies as described herein are advantageously formed to comprise a heat sink monolith and a cover. The heat sink monolith comprises a thermal transfer plate and a wire mesh structure. The thermal transfer plate of the monolith and the cover cooperate to define a heat transfer chamber. The wire mesh structure of the monolith is configured and positioned in the chamber to provide a tortuous, heat conduction path for fluid (e.g., a coolant, such as a liquid coolant) which turbulently travels from an inlet of the chamber to one or more outlets of the chamber. As such, the fluid travels through the chamber in essentially every direction, moving with turbulence and thereby increasing heat transfer capability.

[0040] The wire mesh structure comprises wires which are fused by diffusion bonding (rather than by soldering) into a mesh. For example, the wires comprising the wire mesh structure are fused as a diffusion bond is formed between tangent metal surfaces when enough atoms or molecules migrate between them to create new metallurgical grains which bridge the gap.

[0041] The diffusion bonding of the wires provides the wire mesh structure with many and appropriately sized interstices, making it easier to push the fluid through the heat sink assembly and thereby significantly reducing the size and power of the pump which pushes the fluid. Further, the heat transfer efficiency is increased due to the fact that the diffusion bonded wire mesh structure has such a large surface area. This greater surface area provided by the wire mesh structure facilitates more exposure of the fluid

to the heat transferring metal, and thus a lesser degree of fluid flow, and hence less pressure required for pumping the fluid through the chamber of the heat sink assembly.

[0042] Described herein are non-limiting, representative example embodiments which position a diffusion bonded wire mesh structure in a heat transfer chamber of a heat sink assembly. The heat transfer chamber ("chamber" for short) is primarily defined by a heat transfer plate of the monolith and a cover. The cover has an outlet and an inlet. In the chamber the diffusion bonded wire mesh structure can have various configurations for providing an exposure interface between fluid pumped through the chamber and the diffusion bonded wire mesh. Heat sink assemblies other than those particularly illustrated and described herein are within the purview of the invention. Moreover, the invention is not confined to any particular configuration of one or more elements comprising the heat sink assembly, e.g., not confined to any configuration of the diffusion bonded wire mesh structure or of the chamber or of the cover.

[0043] Fig. 1A, Fig. 1B, and Fig. 1C illustrate a first example embodiment of a heat sink assembly 20-1. The heat sink 20-1 comprises a cover 22-1 and a heat sink monolith 23-1. The cover 22-1 fits over the monolith 23-1 so that a heat transfer chamber 24-1 is defined therein. The monolith 23-1 comprises a thermal transfer plate 25-1 with is integral with a diffusion bonded wire mesh structure 26-1. As in all embodiments described herein, the thermal transfer plate 25-1 is a conductive metal, and preferably the same metal (e.g., copper) as the metal which forms the wires of the wire mesh structure. The wire mesh structure 26-1 of the monolith 23-1 extends into the chamber 24-1.

[0044] Like covers of other example embodiments illustrated herein, the cover 22-1 is essentially a parallelepiped. In fact, the cover 22-1 of the first embodiment is a rectangular parallelepiped having one open face. As such, the cover 22-1 has five walls. The walls of the cover 22-1 include side walls 31-1, 32-1, 33-1, and 34-1, as well as cover wall 35-1. The cover wall 35-1 lies in a plane which is parallel to thermal transfer plate 25-1. When the heat sink assembly is assembled, the open face of cover 22- is closed by thermal transfer plate 25-1. Fig. 1A, Fig. 1B, and Fig. 1C show the heat sink assembly 20-1 with thermal transfer plate 25-1 surmounting the cover 22-1.

[0045] The thermal transfer plate 25-1 can be secured to cover 22 by any suitable fasteners or adhesives such as, e.g., threaded fasteners. Fig. 1B shows the interior of the chamber looking up from cover wall 35-1 toward the underside of thermal transfer plate 30-1, thereby also permitting a view of the diffusion bonded wire mesh structure 26-1.

[0046] Cover 22-1 has an inlet 40-1 through which fluid enters the chamber 24-1 and an outlet 42-1 through which the fluid exits the chamber 24-1. In the first embodiment, the inlet 40-1 and the outlet 42-1 are provided on opposing sidewalls 31-1 and 33-1, respectively, of cover 22-1. Other inlet/outlet arrangements are also possible, including plural inlets on one sidewall and opposing outlets on an opposing sidewall, with inlet(s) and outlet(s) being aligned or non-aligned, etc.

[0047] As with all embodiments described herein, the wire mesh structure 26-1 can be secured or adhered to the thermal transfer plate 25-1 by numerous conventional techniques such as (for example) soldering, welding, radio frequency (RF) melting, and adhesives which are cured or activated (e.g., by heat, by voltage, etc.). The monolithic heat sink comprises a wire mesh formed into a tightly wound spiral which is fused by diffusion bonding (which could be done by soldering, welding, and/or epoxying as well as diffusion bonding to create the monolithic structure) onto the thermal transfer plate.as well as being fused to itself. Preferably in all embodiments the wire mesh structure is diffusion bonded to the thermal transfer plate in a same operation in which the wires of the wire mesh structure are bonded together. The diffusion bonding of the wire mesh structure to the thermal transfer plate to create the monolith allows for higher efficiency in transferring heat from the thermal transfer plate to the wire mesh structure.

[0048] The diffusion bonded wire mesh structure 26-1 is situated in the chamber 24-1 to transfer heat acquired from the thermal transfer plate 30-1 to the fluid in the chamber 24-1 as the fluid is pumped through interstices of the diffusion bonded wire mesh structure 26-1. The wire mesh structure of the monolith is configured and positioned in the chamber to provide a tortuous, heat conduction path for fluid (e.g., a coolant) which turbulently travels from the inlet 40-1 of the chamber to one or more outlets 42-1 of the chamber.

[0049] As shown in Fig. 1C, the diffusion bonded wire mesh structure 26-1 of the first embodiment is folded in an essentially serpentine configuration within the chamber. One such fold axis for the diffusion bonded wire mesh structure 26-1 is depicted as axis 44, which essentially lies along a line parallel to planes of wide wall 31-1 and side wall 33-1. Fold axes are provided at each crest and trough of the serpentine diffusion bonded wire mesh structure 26-1. The fold axes may comprise right angle bends in the manner shown in Fig. 1C, or alternatively may be curved so that the serpentine diffusion bonded wire mesh structure 26-1 has more of an undulating shape rather than the strict zig-zag shape shown in Fig. 1C.

[0050] Due to pumping action, in operation a fluid travels through chamber 24-1 from the inlet 40-1 to the outlet 42-1. Some of the paths of the fluid in the chamber from the inlet 40-1 to the outlet 42-1 are generally depicted by arrows 46-1 in Fig. 1B and Fig. 1C. The paths of fluid travel are thus preferably not parallel to the fold axes 44-1, and more preferably some paths are substantially perpendicular to the fold axes 44-1. Such paths are facilitated by the fact that the inlet 40-1 and the outlet 42-1 are provided on opposing sidewalls 31-1, 33-1, respectively, that are parallel to the fold axes 44-1.

[0051] Fig. 2A, Fig. 2B, and Fig. 2C illustrate a second example embodiment of a heat sink assembly 20-2. Unless otherwise excepted specifically or by context, comments concerning the first embodiment are also applicable to the second example embodiment and other embodiments described herein. For example, the heat sink 20-2 comprises a cover 22-2 which cooperates with monolith 23-2 to define chamber 24-2. A diffusion bonded wire mesh structure 26-2 of monolith 23-2 is situated in chamber 24-2. The cover 22-2 is essentially a square parallelepiped having an open face and has five walls including side walls 31-2, 32-2, 33-2, and 34-2, as well as cover wall 35-2.

[0052] In the orientation of Fig. 2A the cover 22-2 is the uppermost, with thermal transfer plate 30-2 being surmounted by cover 22-2. The thermal transfer plate 30-2 has the diffusion bonded wire mesh structure 26-2 secured to an inside surface thereof by, e.g., diffusion bonding. Fig. 2B shows the interior of the chamber looking up from thermal transfer plate 30-2 toward the underside of cover wall 35-2, thereby also permitting a view of the diffusion bonded wire mesh structure 26-2.

[0053] In the second embodiment, the cover wall 35-2 of cover 22-2 includes both a single inlet 40-2, as well as plural (e.g., four) outlets 42-2. In the illustrated version of the second embodiment, the single inlet is centrally located, while each of the four outlets 42-2 are situated in (e.g., proximate) a separate corner of cover wall 35-2. Other inlet/outlet arrangements are also possible, including plural inlets; greater or lesser than four outlets; differing placements on the cover wall 35-2 of the inlet(s) and/or outlet(s); or even providing the inlet(s) and/or outlet(s) on other walls of cover 22-2.

[0054] As in the other embodiments, the diffusion bonded wire mesh structure 26-2 is situated in the chamber 24-2 to transfer heat acquired from the thermal transfer plate 30-2 to the fluid in the chamber 24-2 as the fluid is pumped through interstices of the diffusion bonded wire mesh structure 26-2. As mentioned previously, preferably the diffusion bonded wire mesh structure is formed integrally with or bonded to the thermal transfer plate 30-2 (e.g., diffusion bonded in the same operation in which the wires of the wire mesh structure are bonded). As shown in Fig. 2C, the diffusion bonded wire mesh structure 26-2 of the second embodiment has an essentially spiral configuration within the chamber. The spiral pattern of the diffusion bonded wire mesh structure 26-2 has a first end near the center of the chamber 24-2 (e.g., near the inlet 40-2), and spirals radially outward toward the side walls of chamber 22-2.

[0055] Due to pumping action, in operation a fluid enters the chamber 24-2 through inlet 40-2 and is directed downward to impinge against the thermal transfer plate 25-2. The impingement action of the fluid against thermal transfer plate 25-2 creates a turbulence in the fluid. The turbulence is beneficial so that a laminar barrier of fluid does not reside on thermal transfer plate 25-2, since a laminar barrier of fluid would tend to buffer the incoming fluid from the heat transfer of the thermal transfer plate 25-2. Moreover, the turbulence to the fluid imparted by the impingement action of the incoming fluid on the thermal transfer plate 25-2 serves to scatter the fluid after the impingement into multitudinous directions and paths through the wire mesh structure 26-2 and thus through the chamber 24-2 toward the outlets 42-2. Some of the paths of the fluid in the chamber from the inlet 40-2 to the outlet 42-2 are generally depicted by arrows 46-2 in Fig. 2B and Fig. 2C.

[0056] Fig. 3A, Fig. 3B, and Fig. 3C illustrate a third example embodiment of a heat sink assembly 20-3. Unless otherwise excepted specifically or by context, comments

concerning the first embodiment are also applicable to the third example embodiment. For example, the heat sink 20-3 cover 22-3 which cooperates with monolith 23-3 to define chamber 24-3. A diffusion bonded wire mesh structure 26-3 of monolith 23-3 is situated in chamber 24-3. The cover 22-3 is essentially a square parallelepiped having an open face and has five walls including side walls 31-3, 32-3, 33-3, and 34-3, as well as cover wall 35-3.

[0057] As in the other embodiments, the diffusion bonded wire mesh structure 26-3 is situated in the chamber 24-3 to transfer heat acquired from the thermal transfer plate 30-3 to the fluid in the chamber 24-3 as the fluid first impinges upon thermal transfer plate 25-3 and then is pumped through interstices of the diffusion bonded wire mesh structure 26-3. As mentioned previously, preferably the diffusion bonded wire mesh structure is formed integrally with or bonded to the thermal transfer plate 30-3 (e.g., diffusion bonded in the same operation in which the wires of the wire mesh structure are bonded). As shown in Fig. 3C, the diffusion bonded wire mesh structure 26-3 of the third embodiment has an essentially circular configuration within the chamber, and preferably is configured to comprise plural concentric rings within the chamber.

[0058] Fig. 4A – Fig. 4F illustrate components of a fourth example embodiment of a heat sink assembly. Unless otherwise excepted specifically or by context, comments concerning the previous embodiments are also applicable to the fourth example embodiment. Fig. 4A and Fig. 4B show monolith 23-4 with its thermal transfer plate 25-4 and its integral wire mesh structure 26-4. Fig. 4C – Fig. 4F show cover 22-4 for the fourth embodiment.

[0059] The thermal transfer plate 30-4 has the diffusion bonded wire mesh structure 26-4 secured to an inside surface thereof by, e.g., diffusion bonding. Although not illustrated in detail in Fig. 4A and Fig. 4B, the wire mesh structure 26-4 can have any suitable configuration. For example, the configuration of wire mesh structure 26-4 can be either the circular configuration of the third embodiment or, more preferably for ease of fabrication, the spiral configuration of the second embodiment. The wire mesh structure 26-4 has an outer diameter and an inner diameter, illustrated in Fig. 4A as OD_{25-4} and ID_{25-4}, respectively. The wire mesh structure 26-4 has a center axis 35-4 which extends essentially orthogonally from the thermal transfer plate 25-4.

[0060] Although the mating of cover 22-4 and monolith 23-4 is not illustrated for the fourth embodiment, it will be appreciated that cover 22-4 fits over monolith 23-4 to define a chamber in similar manner as previously described embodiments. To this end, fastener holes are provided in aligned fashion proximate corners of both thermal transfer plate 25-4 and cover 22-4. The cover 22-4 is essentially a square parallelepiped having an open face and has five walls including side walls 31-4, 32-4, 33-4, and 34-4, as well as cover wall 35-4. The cover 22-4 fits over thermal transfer plate 30-4.

[0061] In the fourth embodiment, the cover wall 35-4 of cover 22-4 includes both a single inlet 40-4, as well as plural (e.g., four) outlets 42-4 (see Fig. 4D). In the illustrated version of the second embodiment, the single inlet 40-4 is centrally located, while each of the four outlets 42-4 are situated in (e.g., proximate) a separate corner of cover wall 35-4. The inlet 40-4 communicates through an inlet channel 50-4 formed in cover 22-4 with an inlet port 51-4 provided on sidewall 31-4 of cover 22-4. The inlet port 51-4 can be threaded or otherwise configured to receive or mate with a tube coupler or the like. Similarly, a pair of two adjacent outlets 42-4 communicate through an associated outlet channel 52-4 to a respective outlet port 53-4 provided on sidewall 33-4 of cover 22-4. The outlet ports 53-4 can also be threaded or otherwise configured to receive or mate with a tube coupler or the like. In the illustrated implementation of the fourth embodiment, the inlet channel 51-4 and the outlet channels 53-4 are perpendicular to the axis of wire mesh structure 26-4, and thus parallel to the plane of thermal transfer plate 25-4. Further, the inlet channel 51-4 and the outlet channels 53-4 have major axes which are parallel to one another. In one example implementation of the fourth embodiment, the diameter of the inlet channel 51-4 is about 0.135 inch while the diameter of the outlet channels is about 0.125 inch. The inlet 40-4 in cover 22-4 has a diameter depicted as D_{40}.

[0062] The orientation of the inlet channel 51-4 and the outlet channels 53-4 as shown with respect to the fourth embodiment facilitates routing of fluid to the heat sink assembly in a direction which is parallel to the plane of thermal transfer plate 25-4, thereby resulting in a shorter form factor which is advantageous for some devices, such as electronic devices including (for example) laptop computers. Other inlet/outlet arrangements are also possible, including further inlets; greater or lesser than four outlets; and differing placements of the inlet(s) and/or outlet(s).

[0063] One example of a different inlet/outlet configuration is shown in a fifth embodiment illustrated in Fig. 5A – Fig. 5E. Elements of the fifth embodiment which are common to the fourth embodiment have similarly numbered reference numerals (excepting suffixes which correspond to the embodiment number). The fifth embodiment essentially differs from the fourth embodiment in that the inlet 40-5 of the fifth embodiment is formed parallel to the axis 35-5 of wire mesh structure 26-5. Thus, the direction of fluid flow

[0064] Preferably the diameter D_{40} of the inlets 40-4 and 40-5 is greater than the inner diameter ID_{25-4} of the respective wire mesh structures 26-4 and 26-5. An example and preferred value for the diameter D_{40} of the inlets 40 is 0.171 inch. By having diameter D_{40} of the inlets 40 be greater than the inner diameter ID_{25} of the wire mesh structures 26, the fluid introduced into the center of the wire mesh structure 26 is constrained into a smaller volume and rebuffed by the wires at the center of wire mesh structure 26. Such constraint and interaction causes turbulence in the fluid and increases the pressure involved in the impingement of the incoming fluid on thermal transfer plate 25. As indicated previously, the impingement on thermal transfer plate 25 causes a further degree of turbulence, which advantageously facilitates greater exposure of the fluid to the metal comprising monolith 23 and thus increased thermal transfer.

[0065] In the fourth embodiment, the right angle bend in the path of the fluid when leaving inlet channel 50-4 and traveling through inlet 40-4 also introduces a measure of turbulence to the incoming fluid. Other ways of providing increased turbulence can also be provided, such as surface irregularities in inlet channel 50-4.

[0066] As in the other embodiments, the diffusion bonded wire mesh structures 26 of the fourth and fifth embodiments are situated in the chamber 24 to transfer heat acquired from the thermal transfer plate 30 to the fluid in the chamber 24 as the fluid is pumped through interstices of the diffusion bonded wire mesh structure 26. As mentioned previously, preferably the diffusion bonded wire mesh structure is formed integrally with or bonded to the thermal transfer plate 30 (e.g., diffusion bonded in the same operation in which the wires of the wire mesh structure are bonded).

[0067] Heat sinks such as the example heat sink assemblies described by way of the non-limiting and representative examples above are useful in a heat dissipation system

in which the thermal transfer plate of the heat sink is situated in heat conducting relation with a body to be cooled, and which further includes a pump and optionally includes a heat exchanger. Although the embodiments illustrated herein include a heat exchange, it is possible in some applications that the heat exchanger may be omitted if there is sufficient cooling of the cooling fluid by remaining elements of the system.

[0068] Fig. 6A illustrates one such heat dissipation system 60A wherein thermal transfer plate 30A of heat sink 20A is in heat conducting relation with body to be cooled 62. An output side of pump 64 is connected by tube 65 to inlet 40 of heat sink 20A. An outlet 42 of heat sink 20A is connected by tube 66 to an intake port of heat exchanger 68. An output port of heat exchanger 68 is connected to an intake side of pump 64. The pump 64 serves to move fluid through a circulation path including tube 65, heat sink 20A, tube 66, heat exchanger 68, and tube 69. The circulation path is configured so that after the heat is transferred to the fluid in the heat sink 20A, the fluid is cooled by the heat exchanger 68 prior to the fluid being circulated back to the heat sink 20A.

[0069] While the heat dissipation system of Fig. 6A is more appropriate for a heat sink having a single inlet and single outlet such as heat sink 20-1 previously described, other versions of appropriate heat dissipation systems can also be designed. For example, the heat dissipation system of Fig. 6B is suitable for a heat sink (such as heat sinks 20-2 and 20-3) having multiple outlets 42. Fig. 6B shows each of the four outlets 42 being connected to an associated tube 66, with the four tubes 66 being connected together or otherwise joined into a single tube 67. Fig. 6B thus illustrates that, in embodiments in which the housing has plural outlets 42, downstream from the outlets the outlets may be connected to a common discharge tube.

[0070] Fig. 6C shows by way of illustration that the pump 64C may be proximate to or formed integral with heat sink assembly 20C. Such juxtaposition of pump and sink can be utilized for various embodiments, not just the particular configuration shown in Fig. 6C.

[0071] Fig. 6D and Fig. 6E show example heat dissipation systems which can be respectively utilized for the fourth and fifth above-described embodiments of heat sink assemblies. The Fig. 6D heat dissipation system is particularly attractive for its low

form factor, especially when the pump 64D, heat sink 20D, and (optional) heat exchanger 68 are located in essentially planar fashion.

[0072] In the heat dissipating systems contemplated herein, the body to be cooled 62 can be any body which generates or radiates heat, such as a die for a microprocessor or other electronic chip, for example. In such case, Fig. 6A and Fig. 6B illustrate a closed loop electronic cooling application for picking up heat generated by a microprocessor or other electronic device.

[0073] The diffusion bonded wire mesh structure is comprised of wire having a suitable gauge and mesh size for the intended application. Mesh size refers to the number of wire strands per linear inch. It is believed that selection of wire gauge and mesh size is interdependent. For a heat sink utilized for the cooling of electronic the diffusion bonded wire mesh structure can have , e.g., a diameter in a range from about 0.0055 inch to about 0.016 inch, and a mesh size less than 100, preferably in a range from about 20 to 80 mesh, and more preferably in a range from and including about 40 mesh to and including about 50 mesh.

[0074] The height of the wire mesh structures 26 described herein, i.e., the extent of the wire mesh structures in a distance perpendicular to the plane of the thermal transfer plate 25, is preferably in a range of from about 0.125 inch to about 0.375 inch.

[0075] The fusing of the wire in the diffusion bonded wire mesh structures allows for higher efficiency in transferring heat from a plate to the diffusion bonded wire mesh. The fusing results in very many channels or interstices in the diffusion bonded wire mesh, making it easier to push the fluid through the heat sink and thereby significantly reducing the size and power of the pump which pushes the fluid. Moreover, the heat transfer efficiency is increased due to the fact that the diffusion bonded wire mesh has such a large surface area. The surface area of a diffusion bonded wire mesh can be as much as or more than five times greater than the surface area of a microchannel type heat sink.

[0076] For all embodiments described herein, the cover 22 can be fabricated from any suitable plastic, such as acetal (e.g., Delrin™ provided by DuPont), PVC, polyethylene, or polypropylene. The cover 22 can also be fabricated from a metal, such as copper.

However, the heat exchange occurring in the chamber 24 appears to be so efficient and effective that the cover 22 need not also be heat conductive. Even in embodiments having a metallic cover there is little noticeable thermal change in the cover. Such being the case, lighter-than-metal materials are preferred for fabrication of the cover.

[0077] In the illustrated embodiments, when pumping 600 ml of fluid less than about 0.5 psi of pressure is required, and preferably about 0.4 psi or less. Thus, the heat sink assemblies operate in a low pressure environment/application, i.e., below 3.0 psi.

[0078] In comparison to microchannels, diffusion bonded wire channels provide more surface area over which fluid can pass. Therefore, diffusion bonded wire channels transfer more heat into the fluid traveling therethrough. Whereas microchannel devices have a discrete and fairly low number of possible (unidirectional) fluid paths, embodiments of the heat sink assemblies described herein have myriad possible paths and combinations of paths through, e.g., the interstices of the wire mesh structure. Moreover, the configurations of the paths and mesh nature of the wire mesh structure, in addition to the impingement effect upon introduction into the chamber, impart turbidity to the fluid. Accordingly, essentially all of the fluid is exposed to the heat transfer metal (e.g., either the thermal transfer plate or the wire mesh structure) at some point in its travel. Further, as mentioned previously, the number of tortuous channels formed by the diffusion bonded wire mesh has low pressure drop.

[0079] While rectangular and/or square parallelepiped housings have been illustrated for the example embodiments, other shape housings are also contemplated. In fact, the housings can be of any geometrical design so long as sized and configured to accommodate the particular diffusion bonded wire mesh structure contained therein. For example, other housing configurations include circular or oval housings, and even housings of irregular shape. Moreover, while the housings of the examples illustrated herein are essentially two piece in having a base plate or thermal transfer plate on one hand and a cover member on the other, the housing can be otherwise formed.

[0080] While the invention has been described in connection with what is presently considered to be the most practical and preferred embodiments, it is to be understood that the invention is not to be limited to the disclosed embodiments, but on the contrary,

is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims.